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EVALUATION OF  
MICROBIAL RELEASE PROBABILITIES

INTERIM REPORT

Contract NASw-2062

National Aeronautics and Space Administration  
Planetary Quarantine Office  
Washington, D.C. 20546

April 1972

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TR72-12

## FOREWORD

This report summarizes work undertaken to obtain an improved estimate of the probability of release of microorganisms from unmanned spacecraft landed on Mars. A description is given of the analytical model used to obtain numerical values for release parameters, and the release mechanisms applicable to flight missions are defined. The report summarizes results of applying this model to obtain parameter values from experimental data developed in related research projects.

The values for microbial release probabilities given in this report have been issued by the Planetary Quarantine Officer for use by flight projects. They were derived with the aid of a procedure established by the Planetary Quarantine Officer to deal with the complexities of parameter evaluation. This procedure comprises an iterative approach with interactions between various groups of researchers, analysts and advisors functioning on behalf of the Mission Project Office and the Planetary Quarantine Officer. Figure i illustrates diagrammatically the interactions among organizations involved in parameter evaluation and approval procedures<sup>1</sup>.

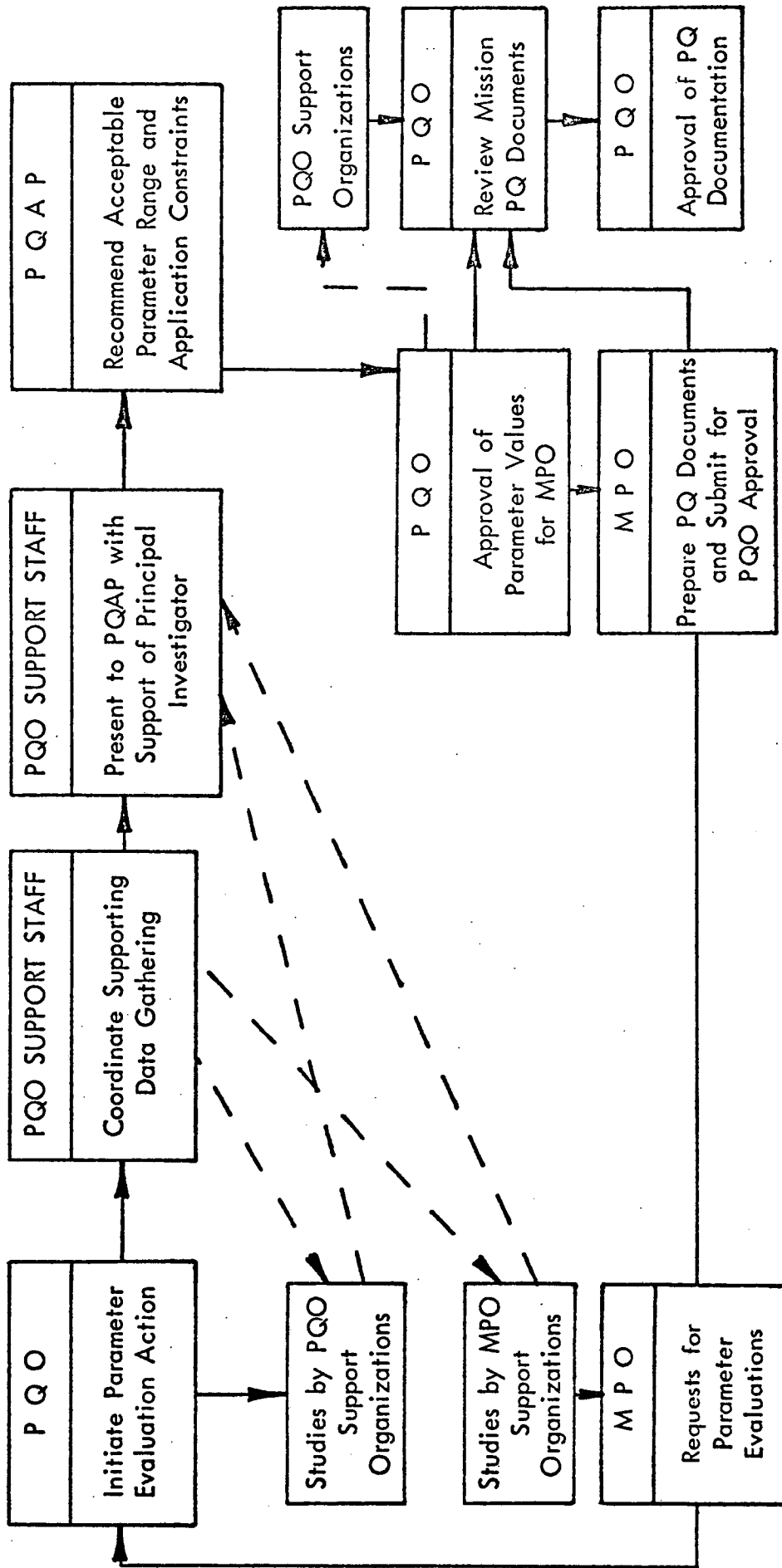
In the present case of microbial release probabilities, major contributions of research and analysis were performed under the auspices of mission project offices by the staff of Bionetics Corporation under the direction of Dr. Joseph Stern, Drs. D.M. Taylor and R.H. Green of the Jet Propulsion Laboratory and researchers of the Boeing Company under the direction of Dr. Richard Olson<sup>2</sup>. Mr. Bruce Nelson of Martin Marietta Corporation made major

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<sup>1</sup> Bond, R.G.; and Brewer, J.H.: Elements in Implementation of Planetary Quarantine Constraints. COSPAR Paper PQ.4, May 1972.

<sup>2</sup> Gustan, E.A.; Olson, R.L.; Taylor, D.M.; and Green, R.H.: Effects of Aeolian Erosion on Microbial Release from Solids. COSPAR Paper L.1.6, June 1971.

# PLANETARY QUARANTINE PARAMETER EVALUATION AND APPROVAL PROCEDURES



PQO - Planetary Quarantine Officer, NASA Headquarters  
MPO - Mission Project Office  
PQAP - Planetary Quarantine Advisory Panel

Figure i

contributions in the analyses, modelling and data gathering of many of the parameters involved. Under the auspices of the Planetary Quarantine Officer research was performed on the survivability of microorganisms under simulated release mechanisms of erosion and impact by Dr. Norman Peterson of the Public Health Service Laboratory, Phoenix. E.J. Bacon, I. Jacoby and R.H. Stroud of Exotech Systems, Inc., under the direction of S. Schalkowsky, performing the required modelling, analysis and coordination of presentations for the parameter evaluations<sup>3</sup>.

Preliminary results of the analyses related in this report were presented at the Spacecraft Sterilization Technology Seminar in Seattle in June 1971. With these data, and the advice of the Planetary Quarantine Advisory Panel, the Planetary Quarantine Officer was able to effect a relaxation in one element of release probability, as follows: Effective September 1971, the value for the probability of release of microorganisms buried in materials landed on Mars was reduced from unity to  $10^{-2}$ ; the values for exposed surface and mated surface release remained at unity.

Results of subsequent analyses were presented for PQAP review in Denver in September 1971 and in Atlanta, in January 1972.

At the January 1972 meeting of PQAP, Mr. Bruce Nelson of Martin Marietta and Mr. I. Jacoby of Exotech Systems made detailed presentations summarizing all available data and the modelling techniques applied in the evaluation effort. These presentations benefited from prior critical reviews and contributions by Dr. Joseph Stern and his associates at Bionetics Corporation. This work resulted in the issuance of parameter values as presented with applicable conditions, constraints and definitions in Appendix A.

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<sup>3</sup>Presented at PQAP Meeting of January 1972, Atlanta, Ga.

The work covered by this report was performed under tasks 5 and 13 of contract NASw-2062, with the objective of developing an analytical and quantitative basis for the estimation of the probability of release, in flight project implementation of programs for heat sterilization and microbial control. Dr. L.B. Hall, Planetary Quarantine Officer, was the contract technical monitor.

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## I INTRODUCTION

Terrestrial microorganisms which may become attached to spacecraft materials during manufacture and test, and carried to the planet, represent a potential source of planetary contamination. The threat which they pose depends upon the likelihood of their removal from the spacecraft, and their ability to grow and proliferate in the local environment in which the spacecraft has landed. A parameter of significance in the quantification of this hazard is the probability that a randomly selected microorganism, contained on or in the landing spacecraft, is released in a viable state. Release, then, is a necessary prerequisite to growth and proliferation; without it, contamination is impossible. A knowledge of the value of the release probability, therefore, is important in the design of sterilization and microbial burden control programs intended to implement planetary quarantine requirements on space flight projects.

Release probability is difficult to quantify accurately. Its enumeration requires a knowledge of; (1) the microbial burden distribution on the landing spacecraft; (2) the planetary landing conditions; (3) the planetary environment characteristics relating to release mechanisms, and (4) the effectiveness of release mechanisms in the escape of viable microorganisms.

The mechanism required to expose microorganisms is related to their location on the spacecraft. For example, the release of microorganisms buried deep within spacecraft material requires a much more potent action than the action to release those located on an exterior surface. Because of the relationship of exposure to location, it is convenient to categorize the total microbial population on the spacecraft into several classes distinguishable by their susceptibility to exposure.

We have, therefore, classified possible microbial burden locations into four classes, ranging from the most readily exposed to the most difficult to expose, as follows:

- . External (unshielded) surfaces
- . Interior surfaces (those, protected by covers, panels, etc.)
- . Mated surfaces (in which microorganisms reside between flanges, joints, seams, etc.)
- . Buried (burden encapsulated within the material)

It is also recognized in this analysis that burden location can influence the ease with which microorganisms can be sterilized. The above classification is consistent with D-value (decimal reduction value) assignments of 0.5 hours for surface, 1 hour for mated surface and 5 hours for encapsulated burden.

Pertinent encounter conditions, which define exposure propensity, include landing parameters (velocity, angle of incidence), and characteristics of the landing site. In our analysis we consider two landing cases:

- (1) a soft landing, in which design stresses are not exceeded, and
- (2) a high velocity impact landing where the closing velocity and other conditions are such that material break-up occurs.

Pertinent planetary environmental characteristics are those which can produce release after landing. Our analysis considers aeolian erosion as a release-conducive environmental characteristic. This phenomenon is defined in terms of wind velocity, particle size, height above terrain, and probability of occurrence.

The fourth factor to be considered in developing numerical values for release probabilities is the effectiveness of any of these mechanisms in releasing

viable microorganisms. In this determination, we have used experimental data to the greatest extent possible. Need for additional experimental and analytical work are cited.

In the absence of reliable data defining these four factors, past missions were assigned a worst-case value of unity for the release probability. Analyses and laboratory work completed during the past year, however, have expanded our ability to quantify these factors. As a result, release probabilities of considerably less than unity are now a reality.

The development of these results was achieved through the use of an analytical model relating the factors involved in microbial release. This model is described in the next section.

## II RELEASE MODEL

The probability of contaminating a planet by terrestrial microorganisms contained on or in a landing spacecraft can be related to the product of the number of microorganisms present, the probability that a randomly selected microorganism in the population will be released in a viable state, and the probability that a released microorganism will grow and proliferate. A simplified model, which ignores factors not directly relevant to the analysis of release probabilities therefore takes the form,

$$P_c = m \cdot P(r) \cdot P(g) \quad (1)$$

where,

- $p_c$  is the probability of contaminating the planet,
- $m$  is the number of microorganisms contained on the lander,
- $p(r)$  is the probability that a microorganism is released in a viable state, and
- $P(g)$  is the probability that the microorganism will grow.

For convenience in considering the probability of release term, equation 1 can be rearranged as follows :

$$\frac{P_c}{P(g)} = m \cdot P(r) \quad (2)$$

In developing the mathematical factors describing the probability of release term, it is instructive to review the release process and its conditions. Microbial release requires the presence of a mechanism or set of actions capable of exposing the microorganism, without causing its destruction through

excessive deformation, pressure, heating or similar stresses. Release is, then, the result of an action which exposes the burden, and the ability of the organism to survive the exposure mechanism. Pertinent mechanisms include mechanical vibrations and shocks, material erosion, chemical action, thermal cycles, and fracturing. Two of these mechanisms are the subject of this analysis. These are:

1. Fracturing, in the landing process, of material containing or shielding the microbial burden.
2. Aeolian erosion of such material.

Our treatment of both mechanisms considers the two underlying phenomena: the exposure action and the survival process.

For simplicity, we have assumed that all microbial burden on external surfaces of landing hardware will be released in a viable state, and that the burden on internal surfaces will escape to the environment if the shielding or protecting medium is removed. In other words, surface burden survival is complete. These assumptions are somewhat more conservative than intuition suggests, but are felt warranted in view of the current lack of knowledge regarding surface release of microorganisms, and the minor effect on final values which a less conservative position would have.

The existence and effectiveness of the two release mechanisms considered depends upon the landing characteristics, and the environmental conditions at the landing site. It is useful to characterize the former in two situations, depending upon landing stresses. A "soft" or nominal landing is one in which there is no breakup of material; a high velocity impact landing is one associated with

the fracturing of material. Therefore, we can consider the probability of release expression in two terms. Hence,

$$P(r) = P(r|s) \cdot P(s) + P(r|I) \cdot P(I) \quad (3)$$

where:

- $P(r|s)$  is the probability of release given a "soft" or nominal velocity landing,
- $P(s)$  is the probability of occurrence of a soft landing,
- $P(r|I)$  is the probability of release given a high velocity impact landing, and
- $P(I)$  is the probability of occurrence of a high velocity impact landing.

Since the probability of achieving a soft landing is close to unity, we can make this approximation, and equation (2) can be simplified to:

$$P(r) \approx P(r|s) + P(r|I) \cdot P(I) \quad (4)$$

By substitution, equation (1) can now be expressed as follows:

$$\frac{P_c}{P(g)} \approx m \cdot P(r|s) + m \cdot P(r|I) \cdot P(I) \quad (5)$$

As previously stated, the process necessary for release depends upon burden location. It is therefore convenient to categorize burden sources, and to treat each separately. These categories are listed in Figure 1, which also summarizes the requirements for exposing the burden contained in each category.

Exposure of contamination on interior or mated surfaces requires the removal of protective material, and the release mechanism must be sufficiently

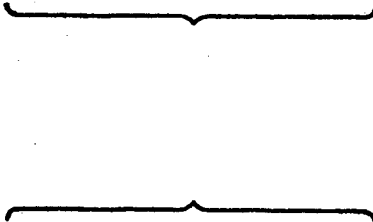
<u>SOURCE CATEGORY</u>	<u>EXPOSURE REQUIREMENT</u>	<u>EXPOSURE MECHANISM</u>
EXTERIOR SURFACE	NONE	-----
INTERIOR SURFACE	REMOVAL OF COVERS & PANELS	
MATED SURFACE	SEPARATION OF FLANGES, WELDS, CRIMPS	
ENCAPSULATED	FRACTURE, CRUMBLING	
		ACCIDENTAL IMPACT
		AEOLIAN EROSION

Figure 1. Source Categorization

potent for removal of the protective material to a prescribed depth before any of the burden can be released. This depth is the thickness of the covers and panels, in the case of interior surfaces, and of flanges and seams, in the case of mated surface burden.

Buried burden is assumed to be uniformly distributed, and its exposure is a linear function of the depth of material eroded.

The significance of this difference in the release profiles of covered surfaces and of buried burden is that covered surface burden can exist without limit, if fracturing and erosion can be shown to be insufficient to overcome the protective thickness. Buried burden, on the other hand, must be enumerated if the probability of occurrence of either fracturing or erosion is finite.

Equation (5) can now be expanded to include the consideration of source categorization, as follows:

$$\frac{P_c}{P(g)} \approx \sum_i m_i P_i(r|s) + \sum_i m_i P_i(r|l) P(l) \quad (6)$$

Where all terms have the same definitions as those previously stated, except with applicability to each of the distinct, individual source categories.

For the 4 source categories enumerated in Figure 1, we can restate equation 6, as follows:

$$\begin{aligned} \frac{P_c}{P(g)} \approx & m_{SX} \cdot P_{SX}(r|s) + m_{SI} \cdot P_{SI}(r|s) \\ & + m_M \cdot P_M(r|s) + m_B \cdot P_B(r|s) \\ & + m_{SX} \cdot P_{SX}(r|l) \cdot P(l) + m_{SI} \cdot P_{SI}(r|l) \cdot P(l) \\ & + m_M \cdot P_M(r|l) \cdot P(l) + m_B \cdot P_B(r|l) \cdot P(l) \end{aligned} \quad (7)$$

where assuming  $P_{SX}(r|s) = 1$  and  $P_{SX}(r|l) = 1$ , the subscripts indicate microbial burden located as follows:

- SX = Exterior Surface,
- SI = Interior Surface,
- M = Mated Surface,
- B = Buried Sources.

From the previously stated assumption that all external surface burden is released in a viable state, the terms  $P_{SX}(r|l)$  and  $P_{SX}(r|s)$  can be set equal to unity. Hence, the microbial release model can be expressed as follows:

$$\begin{aligned} \frac{P_c}{P(g)} \approx & m_{SX} + m_{SI} \cdot P_{SI}(r|s) \\ & m_M \cdot P_M(r|s) + m_B \cdot P_B(r|s) \\ & + m_{SX} \cdot P(l) + m_{SI} \cdot P_{SI}(r|l) \cdot P(l) \\ & + m_M \cdot P_M(r|l) \cdot P(l) + m_B \cdot P_B(r|l) \cdot P(l) \end{aligned} \quad (8)$$

Mathematical development of several of these terms is necessary before numerical solutions can be obtained. This development is summarized in the next section.

### III RELEASE MECHANISMS

The evaluation of the various probability of release terms in equation (8) requires an analysis of the associated release mechanisms. Of the two mechanisms treated here, aeolian erosion will be considered first.

#### EROSION

The current model for release due to aeolian erosion is a relatively simple one. The probability of release is related to the potency of the erosion mechanism in exposing the microbial burden and to the probability that a microorganism survives the erosion process. The former constituent depends upon the rate of erosion and the time duration over which erosion applies.

The relationship for the probability that erosion releases in a viable state a randomly selected microorganism contained within spacecraft material is shown below:

$$P(re|s) = e_i \cdot f_o \cdot t \cdot P(e) \quad (9)$$

where:

$P(re s)$	is the probability of release, due to erosion, of a randomly selected microorganism soft landed on the planetary surface,
$e_i$	is the rate at which landed material is eroded,
$f_o$	is the initial fracture ratio expressed as the ratio of exposed surface area to volume of the landed hardware,
$t$	is the period of time that the material is subjected to erosion during the quarantine period,
$P(e)$	is the probability that a buried microorganism survives the erosion process.

The rate at which material is being eroded,  $e_j$ , has as its unit of measure a linear depth per unit time; for example,  $10^{-6}$  meters of material per year. The amount of material eroded depends upon the area exposed to erosion. We express this factor in terms of an area to volume,  $f_o$ .

The time,  $t$ , during which spacecraft materials would be subject to erosion is taken to be the prescribed period of planetary quarantine.

Allowance is made for the possibility that if the erosion mechanism is of substantial energy, it can cause the destruction of microorganisms while it is effecting their release. A term,  $P(e)$ , describing the probability of surviving the erosion process is, therefore, also incorporated into the erosion model.

The greatest uncertainty in the evaluation of equation (9) involves the erosion rate and survival probability terms. Both theoretical and empirical studies have been undertaken to provide data for reducing the spread of numerical values. Appendix A presents an analysis of erosion characteristics based upon laboratory test data, and postulated environmental conditions for the planet Mars. Other laboratory data considered included sand blast erosion of seeded pellets with measurement of particle velocity, erosion rate, and percent of survivors. Results of the tests, conducted by the Boeing Company, are presented in Figure 2. Of significance are the high apparent lethality associated with the process, and the weak or absent correlation of lethality with the rate of erosion.

Attempts were made to extrapolate these results to the Martian situation. The environmental conditions postulated in the Viking Engineering Model were used. Figure 3 shows a comparison of the model and the laboratory tests in terms of particle velocities and sizes. The significantly lower velocities postulated for Mars raise a question of the degree to which one can extrapolate the lethality results. Earlier estimates of complete spacecraft erosion over the

# EXPERIMENTAL RESULTS

Medium	Particle Velocity ft/sec	Rate of Erosion m/yr	Fraction of Survivors	
			Methyl Methacrylate	Eccobond
CO <sub>2</sub>	300	30	$1.1 \times 10^{-3}$	$3 \times 10^{-4}$
AIR	375	30	$2 \times 10^{-4}$	$2 \times 10^{-5}$
	334	7.5	$1 \times 10^{-4}$	$2 \times 10^{-4}$
	185	0.6	$2 \times 10^{-4}$	$1 \times 10^{-4}$

Figure 2. Results of Erosion of Seeded Pellets

<u>VIKING ENGINEERING MODEL</u>	<u>EXPERIMENTAL CONDITIONS</u>
<u>PARTICLE VELOCITIES</u>	
$\approx 30 \text{ ft/sec} - (10^\circ \text{ N} - 42^\circ \text{ S summer solstice})$	Aluminum oxide 420 ft/sec
$\approx 20 \text{ ft/sec} - (42^\circ \text{ N} - 10^\circ \text{ N summer solstice})$	Aluminum 220 ft/sec
<u>PARTICLE SIZE</u>	
100% > $1 \mu$	210 $\mu$
75% > $15 \mu$	
50% > $40 \mu$	
25% > $300 \mu$	
Average $\approx 200 \mu$	

Figure 3. Comparison of Erosion Test Conditions  
with Postulated Martian Environmental Parameters

20 year quarantine period appear to be unsupportable by the postulated environmental conditions of the Viking Engineering Model.

The estimate that there will be some degree of erosion, however, can be supported by these data. Figure 4 presents erosion rate values for aluminum and lucite, based upon a velocity scaling factor described in Appendix A. Equivalent values for the probability of a randomly selected microorganism being released by erosion are presented in Figure 5. Approximate confidence limits are indicated to assist in parameter value selection.

It should be noted that the lethality attendant to the erosion rate values is probably applicable only to the buried source category. For interior surface and mated surface burden, erosion serves as an escape mechanism by removing a cover, panel or flange. The degree to which this removal process kills the microbial burden which is exposed by the process is probably less than that for the buried burden case, where the microorganism being released will be directly exposed to blasting effects of the erosion mechanism.

Since the completion of this erosion analysis, the Mariner 9 mission has encountered Mars, and data regarding Martian environmental conditions have become available. These results suggest considerably higher wind velocities and more extensive erosion than indicated by the Viking Engineering Model and cast serious doubts on the validity of the latter data. Release parameter values presented in Section IV and Appendix B have, therefore, been based extensively on wind velocities and erosion conditions postulated from Mariner 9 observations.

BASED UPON VIKING ENGINEERING MODELS

Assumed Particle Velocities —  $\approx 30$  ft/sec

Assumed Particle Sizes —  $200\mu$  average

Aluminum — 3 to  $30\mu$  m/year

Lucite — 3 to  $30\mu$  m/year

Figure 4. Estimated Erosion Rates on Mars

CONFIDENCE	Prob. of Exposure by Erosion	Prob. of Surviving Release	ESTIMATED VALUE
0.99	$10^{-1}$	$10^{-3}$	$10^{-4}$
0.50	$10^{-2}$	$10^{-3}$	$10^{-5}$
0.10	$3 \times 10^{-3}$	$7 \times 10^{-4}$	$2 \times 10^{-6}$

Figure 5. Estimated Probabilities of Release by Erosion  
for Buried Organisms

## IMPACT

An analysis of impact as a microbial release mechanism has been reported earlier<sup>1/</sup>. The process assumes material fracturing which can expose burden located along the fractures. The factor is expressed in terms of the potential exposure action and the probability that the microorganism survives. Impact exposure depends upon the extent of fracturing and the material depth along the fracture within which a microorganism can escape. Equation (10) shows the relationship for probability of release as an immediate consequence of a fracturing impact, as follows:

$$P(r)I = P(I) \cdot f(v) \cdot g(v) \cdot \lambda \quad (10)$$

where,

$P(r)_i$  is the probability of release of a randomly selected encapsulated microorganism as an immediate consequence of impact.

$P(I)$  is the probability that a fracturing impact occurs.

$f(v)$  is the fracture ratio resulting from the fracturing impact.

$g(v)$  is the probability that a buried microorganism survives fracture.

$\lambda$  is the depth coefficient, or the depth from which a microorganism can escape.

Our development of equation (10) recognizes the velocity dependance of the  $f$  and  $g$  terms, and bounds the  $f \cdot g$  product as a function of landing velocity. The result is shown in Figure 6.

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<sup>1/</sup> Exotech Systems, Inc., Washington, D.C.: Analysis of Microbial Release Probabilities. Interim Report TR71-11, (contract NASw-2062), Dec. 1970.

# FRACTURING FACTOR

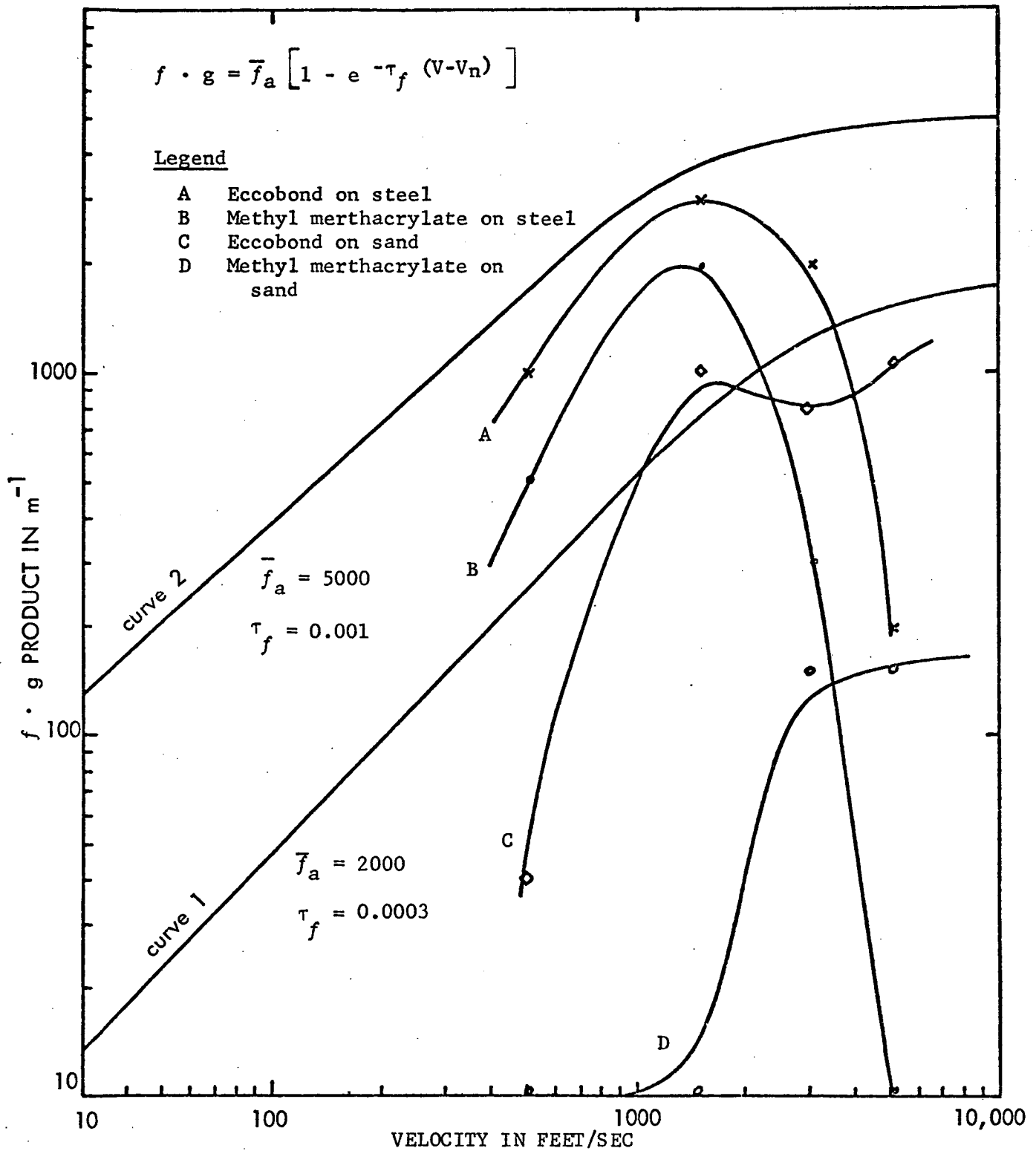


Figure 6. Fracturing Produce vs. Impact Velocity

The four curves (A, B, C, and D) shown in this figure were derived from laboratory tests, conducted by the Boeing Company, on inoculated methyl methacrylate and eccobond pellets impacted at various velocities on sand and stainless steel targets. Boeing test results for percentage of spores (both surface and buried) surviving impact were averaged over the various initial spore levels used. The fracture ratio values for these curves were obtained by us from observation of pellet fragments provided by the Boeing Company.

Two experimental curves were fit to these data. They are of the form:

$$f \cdot g = f_a \left[ 1 - e^{-\tau_f (v - v_n)} \right] \quad (11)$$

where,

- $f_a$  is the asymptotic value of the curve,
- $\tau_f$  is a time constant factor describing the steepness of the curve,
- $v$  is the impact velocity,
- $v_n$  is the soft landing velocity.

The two curves were selected to permit the determination of the sensitivity of this factor in the quantification of the probability of release term. Curve 1 was intended as a median fit; and curve 2 as a limiting case in the conservative direction. The former contains almost all data points for sand impact, but is an optimistic approximation if Martian impact produces results similar to pellet impact on steel. Curve 2, on the other hand, bounds all test observations.

Our treatment of the probability of impact term recognizes a similar velocity dependence. Figure 7 shows the relationship in terms of a distribution function,  $f(v)$ .

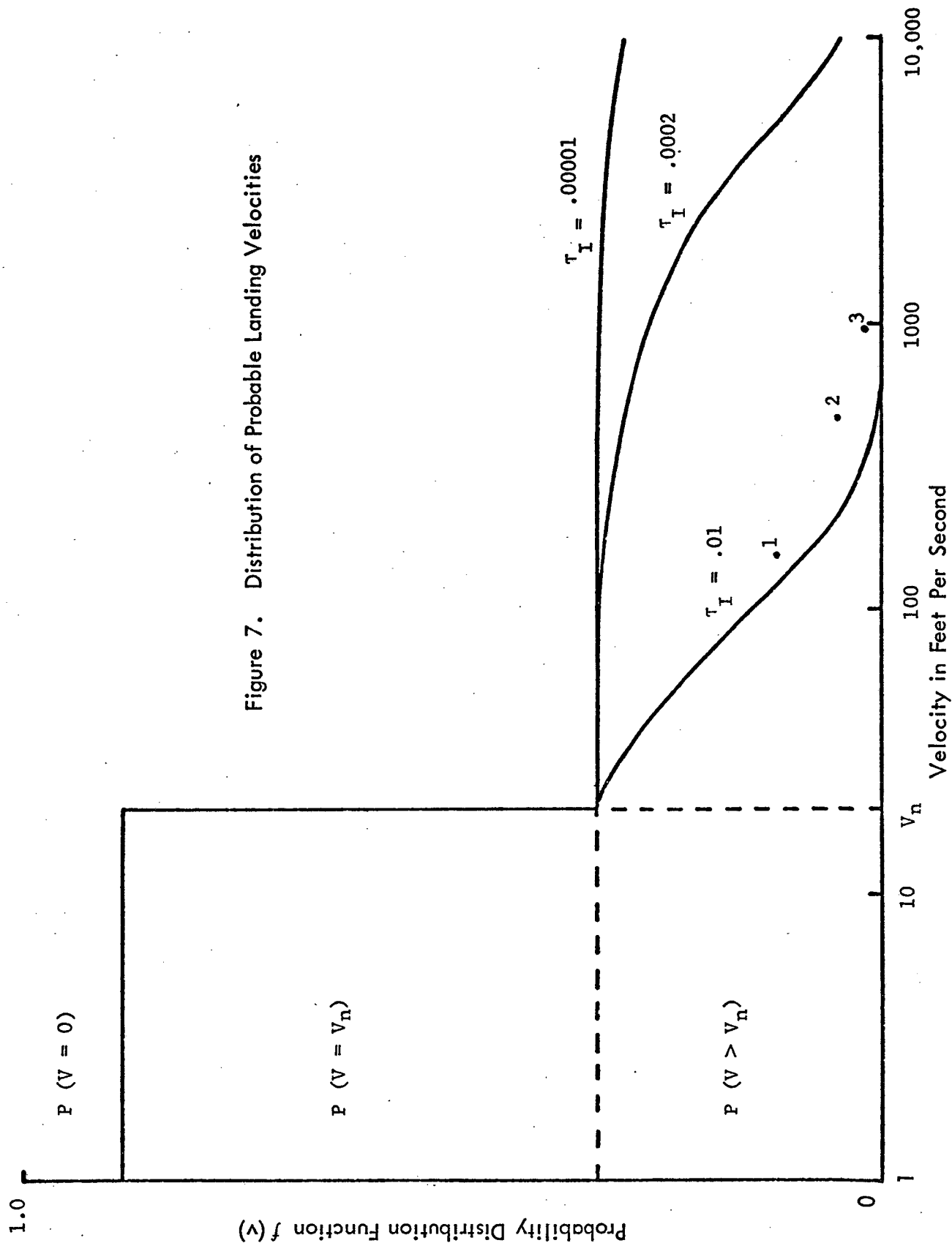


Figure 7. Distribution of Probable Landing Velocities

The value of  $f(v)$  at any velocity,  $v$ , is the probability that the landing velocity is equal to or greater than  $v$ . A hypothetical curve for  $f(v)$  plotted against landing velocity is presented in the figure.  $f(v)$  has a value of zero at zero velocity, and jumps to a high value at the soft landing velocity range (assumed in this plot to extend to 20 feet per second). The difference between this high value and 1.0 is the probability that the spacecraft fails to reach the planet surface.

Ideally, the probability that the landing velocity is greater than the soft landing velocity would be zero, but malfunctions during approach, which can cause crash velocities, are possible. The term  $P(l)$  represents the total probability of such malfunctions, and its distribution over the velocity range is represented in the  $f(v)$  plot by three hypothetical exponential curves. The term  $\tau_l$ , used to characterize the velocity distribution of  $P(l)$ , is the reciprocal of the time constant for each exponential curve, and is a measure of the rate at which the curve approaches zero. The higher the value of  $\tau_l$ , the smaller is the spread of possible values for impact velocities.

Three possible Viking spacecraft descent system malfunctions are identified on the plot as points 1, 2, and 3. The pertinent data for these three points are:

<u>Point #</u>	<u>Applicable Malfunction</u>	<u>Mean (fps) Velocity</u>	<u>Individual Probability of Occurrence</u>	<u><math>f(v)</math> Value</u>
1	Parachute not cut	180	0.0015	.0037
2	Aeroshell does not separate	570	0.0002	.0022
3	Venier engine fails to ignite	1000	0.002	.002

The expression for the assumed exponential portion of the distribution function of landing velocity,  $f(v)$ , is:

$$f(v) = P(I) \cdot e^{-\tau_I (v - v_n)} \quad (12)$$

where the terms are as defined previously.

Ranges of parameter values developed by analysis of experimental and theoretical data are shown below:

	<u>Conservative</u>	<u>Most Probable</u>
$\lambda$ (meters)	$3 \times 10^{-6} \text{ m}$	$1 \times 10^{-6} \text{ m}$
$f_a$	$5000 \text{ m}^{-1}$	$2000 \text{ m}^{-1}$
$P(I)^*$	$10^{-1}$	$10^{-3}$
$\tau_f$	$1 \times 10^{-3}$	$3 \times 10^{-4}$
$\tau_I^*$	$10^{-4}$	$10^{-2}$

\*Values to be developed by project through reliability analysis.  
Values indicated are representative only.

The total expression for the probability of microbial release as an immediate consequence of impact is:

$$P(r)_I = \lambda \int_{v_n}^{\infty} \bar{f}_a \left[ 1 - e^{-\tau_f (v - v_n)} \right] \tau_I \cdot P(I) \cdot e^{-\tau_I (v - v_n)} dv \quad (13)$$

By integration, this expression reduces to:

$$P(r)_I = \lambda \cdot \bar{f}_a \cdot P(I) \cdot \frac{\tau_f}{\tau_f + \tau_I} \quad (14)$$

Because of the project-specific nature of two of the five factors enumerated above, it is difficult to develop a single valued specification for this parameter. The approach which we have selected is to state the conditions under which this parameter is no longer significant in comparison with the erosion release term and hence need not be considered further in the release estimation process. The feasibility of this approach has been demonstrated using data from the Viking '75 project. Assuming that a value of  $10^{-3}$  can be substantiated for  $P(I)$  for Viking, and using conservative values for the other factors in equation (14) we find that:

$$P(r)_I = 1.5 \times 10^{-5} \cdot \frac{10^{-3}}{10^{-3} + \tau_I} \quad (15)$$

If  $\tau_I \geq 10^{-2}$  then  $P(r)_I$  becomes  $1.5 \times 10^{-6}$ , which is small enough to be ignored in relationship to the value ( $10^{-4}$ ) specified for the probability of release of buried burden caused by erosion. A value of  $\tau_I \geq 10^{-2}$  requires that the probability of landing at a velocity of 1000 ft/sec or greater should be at least 4.4 orders of magnitude smaller than the total probability of impact.

One of the parameter specifications issued to flight projects is that for the impact portion of the probability of release of buried burden. The related procedure requires determination by the flight project of the probability of impact, and of the distribution of impact velocity ( $\tau_I$ ). Based upon these values relative to stated conditions, the specification may or may not be applicable. The determination is to be made by those responsible for the PQ analysis for each specific flight project.

#### IV PARAMETER ESTIMATION

A set of release probability parameters has been formulated for use by flight projects in establishing compliance with Planetary Quarantine constraints. Numerical values for these parameters based upon the analysis and research described in earlier sections have now been specified. In the establishment of these specifications, research results were carefully reviewed by the Planetary Quarantine Office with the consultation of the Planetary Quarantine Advisory Panel. Recommendations for flight project implementation of the results of this work were presented by Exotech Systems, Inc., to PQAP on January 18-19, 1972 at Cape Kennedy, Florida. The release parameters and their values described in this section resulted from that review. Although these parameters are unique to Martian landing missions, extrapolations to other types of missions and to other planets are possible.

A total of 6 parameters have been specified, three applicable to soft landing, and three to high velocity impact landing. Each group of 3 covers three categories of microbial burden;

- . external and internal surfaces
- . mated surfaces
- . buried surfaces

External and internal surface burden has, for the sake of convenience, been combined into a single term in release consideration. The value for the release probability term associated with soft landings is provided as a range, the high end of which is related to the more easily released external burden, while the low is equated with the better protected internally shielded burden. In flight project application of this term, the use of low range values must be justified in terms of the integrity of the shielding structure or of microbial kill resulting from its removal.

As previously stated, only two release mechanisms were considered in the development of this set of parameters. They are intended to be applicable, however, to all possible release processes.

Parameter applicability is shown in the following table:

#### PARAMETER TO BE USED

<u>Burden Category</u>	<u>Soft Landing</u>	<u>High Velocity Impact</u>
Buried	$P_B(re s)$	$P_B(r I)$
Mated Surface	$P_M(re s)$	$P_M(r I)$
External Surface	$P_{SX}(re s)$	$P_{SX}(r I)$
Internal Surface	$P_{SI}(re s)$	$P_{SI}(r I)$

#### SOFT LANDING RELEASE PARAMETERS

The parameter that expresses the probability that a randomly selected buried microorganism, within a defined source, will be removed from that source by aeolian erosion, and deposited on the surface of the planet in a viable state, is shown as  $P_B(re|s)$ .

Based upon Mariner 9 observations, the likelihood seems high that extensive erosion of spacecraft hardware will be experienced by a Martian lander at some time during the quarantine period. There is, therefore, a high probability that erosion will expose buried microbial burden and provide the means for its release. Because of the attendant high erosion rate, however, a low probability of survival ( $10^{-4}$ ) was estimated. The value of the probability of release of buried burden due to erosion is therefore taken at  $10^{-4}$ .

Assuming soft landing of a spacecraft on Mars, the parameter that expresses the probability that a randomly selected microorganism from a mated surface, within a defined source will be removed from that source by erosion, and deposited on the surface of the planet in a viable state, is shown as  $P_M(re|s)$ .

Again, complete erosion of mated flanges and seams appears likely. Because of the concentration of the burden and its instantaneous exposure, once the protective material has been removed, postulating the same degree of lethality appeared overly optimistic. A value of  $10^{-3}$  was therefore selected.

The parameter that expresses the probability that within a defined source, on the surface of a soft landed Martian spacecraft, a randomly selected microorganism will be removed from that source by aeolian erosion, and deposited on the surface of the planet in a viable state, is shown as  $P_S(re|s)$ .

Similar reasoning to that above results in the conclusion that all surface contamination (both external and internal) will be exposed. The probability of surviving release is estimated to range from  $10^{-2}$  to 1, according to the amount of erosion required to expose the microorganism.

## HIGH VELOCITY IMPACT LANDING RELEASE PARAMETERS

The parameter that expresses the probability, assuming high velocity impact landing of the spacecraft on Mars, that a randomly selected microorganism encapsulated within spacecraft materials will be removed by the combined mechanisms of fracture during impact and subsequent erosion, and deposited on the surface of the planet in a viable state is shown as  $P_B(r|I)$ .

As defined above, this term is comprised of two factors:

- (1) release as a result of erosion of the impacted materials, and
- (2) release as an immediate consequence of impact.

The first factor has been assigned a value of  $10^{-4}$  by the same reasoning as that for  $P_B(re|s)$ . The second is estimated to be negligible, relative at first, provided these two conditions are met:

- (1) The probability of accidental impact with fracturing is less than  $10^{-3}$ .
- (2) The probability that the landing velocity is 1000 ft/sec or larger is 5 orders of magnitude smaller than the total probability of accidental impact.

The parameter that expresses the probability, assuming high velocity impact landing of the spacecraft on Mars, that from a randomly selected mated surface, a microorganism anywhere in the spacecraft will be removed by the combined mechanisms of fracture during impact and subsequent erosion, and deposited on the surface of the planet in a viable state, is shown as  $P_M(r|I)$ .

As above, this parameter consists of two terms:

- (1) the immediate release of microbial burden as a direct consequence of breakup of the spacecraft hardware, and
- (2) the release of mated surface microbial burden due to erosion subsequent to a fracturing impact.

Although our analysis of the effect of crash impacts is continuing, preliminary indications show that mated joints and seams were generally more

susceptible to breakup than were solid materials under similar stress conditions. As a result, we estimate that the probability that mated surface burden will be exposed in an accidental impact landing is  $10^{-1}$ .

Because these microorganisms are less firmly bonded to the material than encapsulated burden, it is expected that release survival will also be greater. Lacking experimental evidence to the contrary, we have selected a value of 1.0 for the probability of such survival. Therefore, the value for the probability of release is the product of these two factors or  $P_M(r|I) = 10^{-1}$ .

The parameter that expresses the probability, assuming high velocity impact landing velocities of the spacecraft on Mars, that a randomly selected organism located on a surface will be removed by the combined mechanisms of impact and subsequent aeolian erosion, and deposited on the surface of the planet in a viable state, is shown as  $P_S(r|I)$ .

This parameter is a composite of external and of internal burden. Release of the former should be almost complete, with some kill of those microorganisms caught between compressing materials; thus a value close to unity is estimated for this component. The latter constituent can also be expected to have a high release probability, either as an immediate consequence of impact, or from subsequent erosion. Based upon these considerations, a value of 0.5 has been selected for this parameter.

## V CONCLUSIONS AND RECOMMENDATIONS

The microbial release model of equation (8) can now be enumerated using the estimated values developed in Section IV.

The resultant expression becomes:

$$\frac{P_c}{P(g)} = m_{SX} + 10^{-1} m_{SI} + 10^{-3} m_M + 10^{-4} m_B \quad (16)$$

Negligible terms have been dropped and a mid-range value of  $10^{-1}$  was taken for  $P_S(r|s)$ . The conditions and restrictions used in the numerical parameter development of Section IV obtain.

Equation (16) can be used to develop flight project contamination control strategies, identify governing sources in the estimation of contamination probability and assist in the suballocation of the mission contamination constraint.

With some extrapolation the complete set of release parameters specifications for Martian lander missions can be applied to other missions and other planets. Further work in this extrapolation is indicated to assure useful values without undue conservatism.

The parameter values resulting from this work have been found useful to the Viking project. Although this project is rapidly approaching a cut-off date where subsequent relaxations will not influence control procedures, some further efforts are recommended.

A sensitivity analysis should be conducted to establish priorities of effort based upon anticipated benefit to flight projects. Should the above analysis

reveal the following areas as worthy of investigation, efforts should be undertaken to reduce current uncertainties.

- (1) Further work is needed to define release from material surfaces. Pertinent laboratory and analytical work should be performed, so that gaps in current knowledge may be identified. Research should be undertaken to identify release mechanisms, to quantify lethality, and to develop improved estimates for surface release parameters.
- (2) Additional analysis is suggested on the effects of crash impact on the release of mated surfaces burden, including the survival probabilities.
- (3) Additional knowledge is needed in the area of release of mated surface burdens caused by erosion. The postulated reduced lethality factor for mated surface release, as compared with that from buried release, should be verified.

## APPENDIX A

### ESTIMATION OF MARTIAN AEOLIAN EROSION PARAMETERS

## APPENDIX A

### EROSION RATE

The rate at which a structure on the Martian surface will erode is dependent on the type of material exposed to the eroding environment, the amount and size of eroding particles, and the wind velocity to which the structure is exposed. The relationship postulated here to describe this erosion rate is

$$e_r = \frac{m_e}{m_i} f(v) \Phi(v) v \frac{c}{\rho}$$

where the various terms are

$$\frac{m_e}{m_i} = \text{mass eroded for a given mass impacted,}$$

$$f(v) = \text{a velocity dependent proportionality factor associated with } m_e/m_i,$$

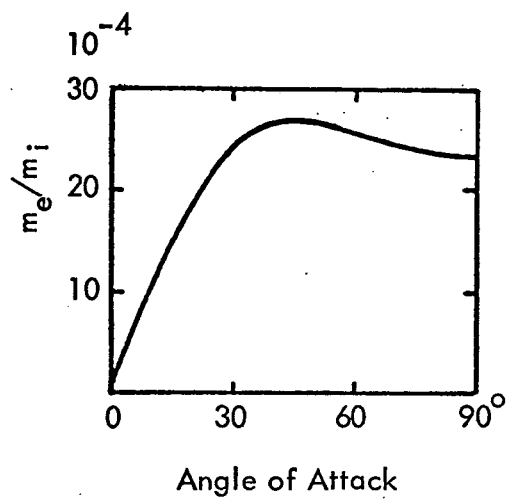
$$\Phi(v) = \text{the mass of eroding material carried by the wind in a given volume as a function of wind velocity,}$$

$$v = \text{the velocity of the impacting particles,}$$

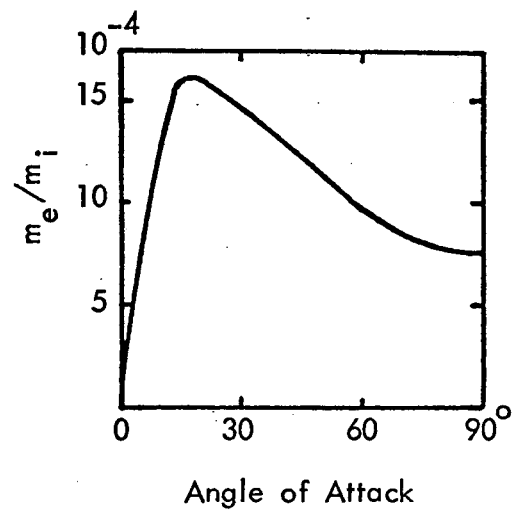
$$c = \text{a constant associated with dimensional conversion,}$$

$$\rho = \text{the density of the eroded material.}$$

The ratio of mass eroded to mass impacted as a function of impact angle is given by Neilson and Gilchrist in reference 1 for lucite exposed to a 420 ft/sec wind and for aluminum exposed to a 220 ft/sec wind. These values are shown in Figure A-1. The eroding materials for the lucite and aluminum are 210 $\mu$  aluminum oxide particles and 210 $\mu$  aluminum particles, respectively. It



(a) Erosion vs. angle of attack characteristic for lucite eroded by  $210\mu$  aluminum oxide particles at 420 ft/sec



(b) Erosion vs. angle of attack characteristic for aluminum eroded by  $210\mu$  aluminum particles at 220 ft/sec

Figure A-1. Erosion vs. Angle of Attack

is assumed that the effect of these particles is representative of that which would occur on the Martian surface. In order to extrapolate this data to other velocities, it is now necessary to determine the velocity-dependent factor  $f(v)$ . It is assumed that this factor is of the form  $f(v) = (v/v_{ref})^P$ , where  $v_{ref}$  is the velocity used to determine the curves of Figure A-1, and the exponent  $P$  is dependent on the mechanism of erosion. If the erosion mechanism is a transfer of momentum from the impacting particle to the eroded material, the  $P = 1$ . If it is a transfer of kinetic energy  $P = 2$ . Both cases will be considered. The value of  $\Phi(v)$  at a wind velocity of 220 ft/sec is taken as  $(1.25 \pm 0.25) \times 10^{-4}$  oz/ft<sup>3</sup> for a simulated Martian atmosphere (refs. 2 and 3). It is further assumed that the relationship between  $\Phi(v)$  and  $v$  is linear. That is, for any given wind velocity  $v$ ,  $v > v_{\tau}$ ,

$$\Phi(v) = (1.25 \pm 0.25) \cdot 10^{-4} \left( \frac{v}{v_{\tau}} - 1 \right) \left( \frac{220}{v_{\tau}} - 1 \right)^{-1}$$

where  $v_{\tau}$  is the threshold velocity in ft/sec for dust mobility on Mars. The velocity of  $v$  of the wind is taken as the velocity of the impacting particles. The product of this velocity and the mass of material  $\Phi(v)$  carried by a volume element yields the mass striking an area element per unit time. The values of the density  $\rho$  were taken as 1.185 gm/cm<sup>3</sup> for lucite, and 2.7 gm/cm<sup>3</sup> for aluminum (ref. 4). The constant  $c$  is determined from dimensional conversion factors so that  $e_r$  will be given in cm/year.

## MARTIAN WINDS

The erosion relationship of the previous section is a function of wind velocity and threshold velocity for dust mobility. It is left then to determine these velocities on the Martian surface.

Figures A-2 and A-3 are probability histograms for wind speed at the top of the boundary layer (approximately 1000 m) for two latitude bands at the time of the summer solstice in the northern hemisphere (ref. 5). Also shown is the cumulative probability of the wind speed being equal to or less than a given value. For purposes of calculation, the median value is taken as representative. For Figures A-2 and A-3, these values are 82 ft/sec and 50 ft/sec, respectively.

Figure A-4 (ref. 5) shows the relationship between the wind velocity  $v$  within the boundary layer and the free stream velocity  $v_{fs}$  at the outer edge of the boundary layer. The range shown in the figure between two limiting profiles is assumed to cover both thermally stable and unstable boundary layers. The smaller values of velocity ratio represent the stable case, and the larger values the unstable case. Periods of neutral stability of the boundary layer are expected to occur in the morning and in the evening. During these periods the value of  $v/v_{fs}$  is expected to be approximately  $0.35 \pm 0.10$  at an altitude of 1 meter. Later at night when high stability occurs, the value at 1 meter is expected to be between 0.15 and  $0.35 \pm 0.10$ . In the afternoon when the boundary layer becomes unstable, the value of  $v/v_{fs}$  at 1 meter is expected to be between  $0.35 \pm 0.10$  and 0.60. In conjunction with the median values of  $v_{fs}$  from Figures A-2 and A-3, the median wind velocity  $v$  at 1 meter will range between 2.3 and 49.2 ft/sec between  $10^\circ$  N and  $42^\circ$  S, and between 8.0 and 30.0 ft/sec between  $42^\circ$  N and  $10^\circ$  N.

The threshold velocity  $v$  for dust mobility can be approximated from Figure A-5 (ref. 6). The minimum value of this velocity occurs for particles with a radius near  $200\mu$ . Since a large portion of the Martian surface is assumed to be composed of this size particle (ref. 5), it will be assumed that this determines a lower bound for  $v_\tau$ . If the surface pressure is taken as approximately 5.3 mb (ref. 5), the result for the lower bound is  $v_\tau = 11$  ft/sec.

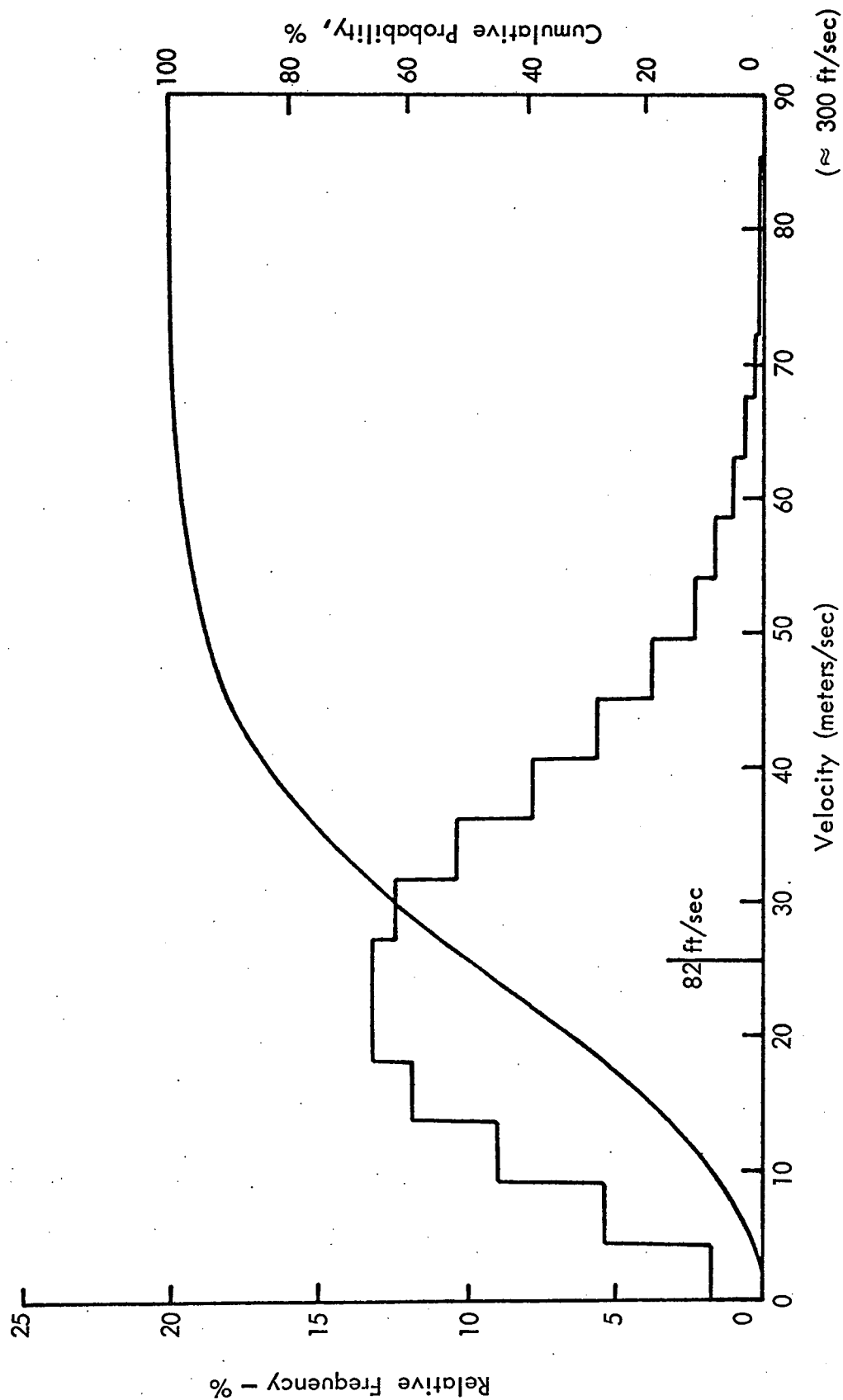


Figure A-2. Probability distribution of near-surface wind speed on Mars  
between 10° N and 42° S latitude near the summer solstice  
in the northern hemisphere (ref. 5)

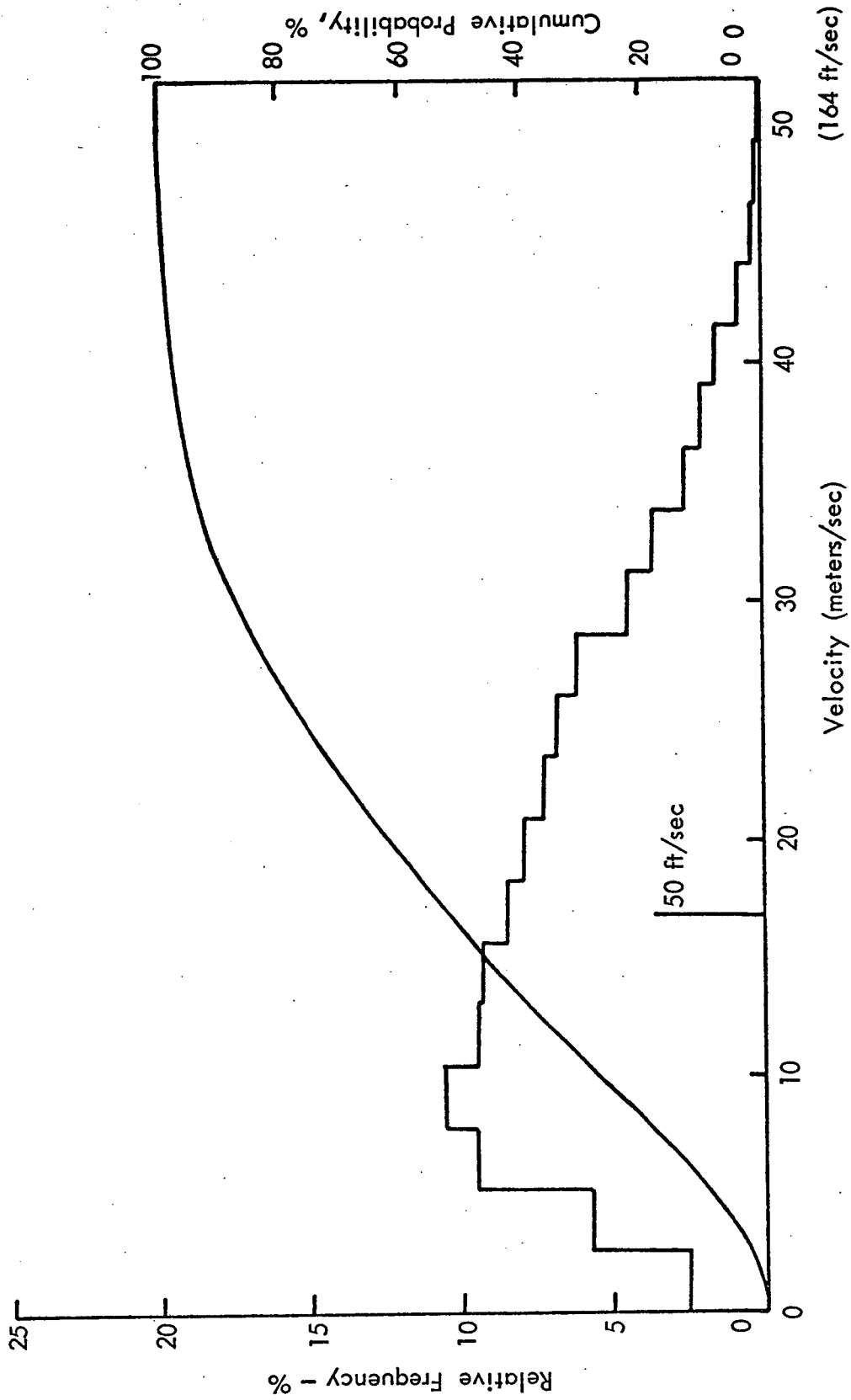


Figure A-3. Probability distribution of near-surface wind speed on Mars between 42° N and 10° N latitude near the summer solstice in the northern hemisphere (ref. 5)

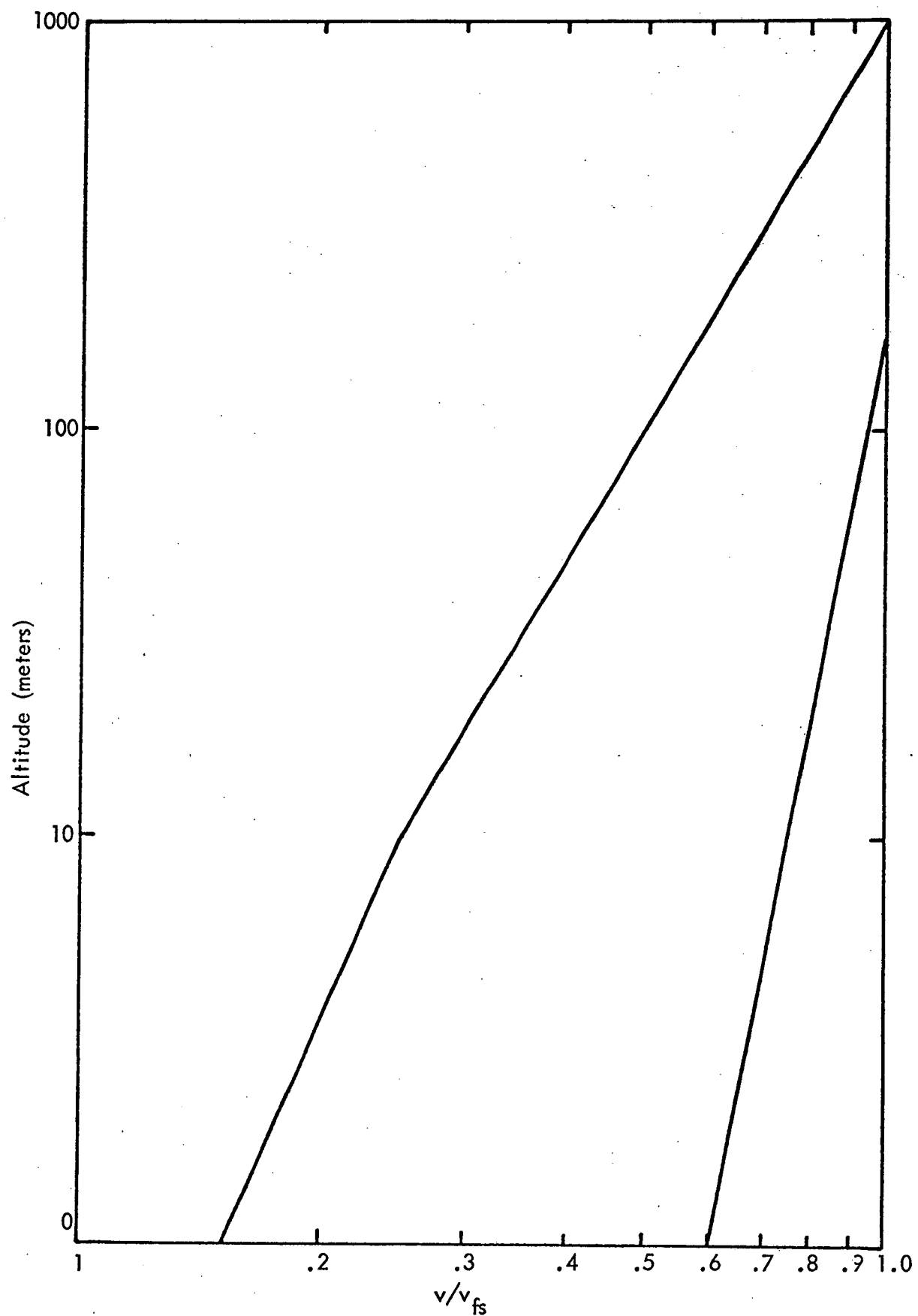


Figure A-4. Limiting profiles of velocity in boundary layers on Mars  
(ref. 5)

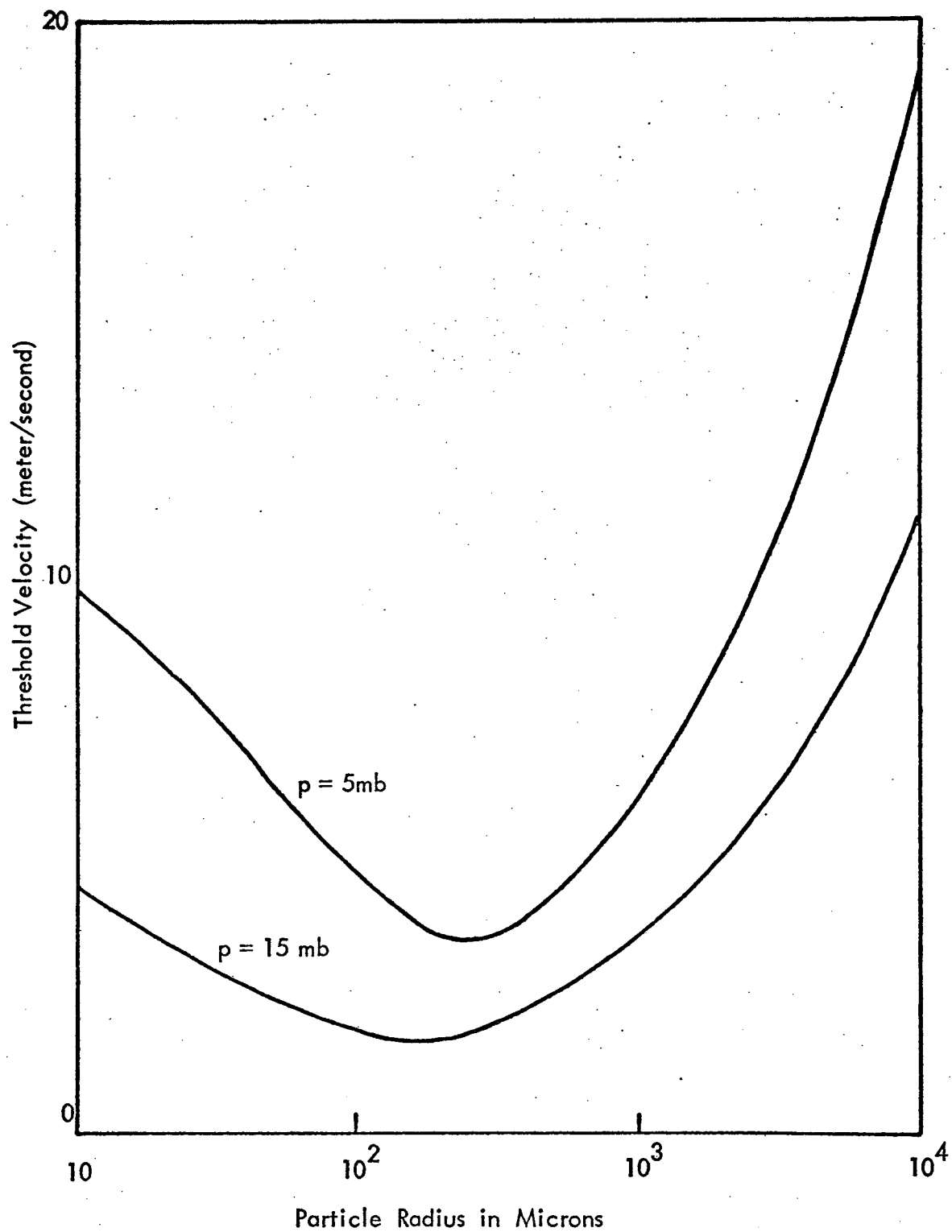


Figure A-5. Threshold velocity for dust mobility on Mars as a function of particle radius, for two choices of total surface pressure (ref. 6)

## CALCULATED EROSION RATES

The erosion rate  $e_r$  was calculated for lucite and aluminum, using both  $P = 1$  and  $P = 2$  over a range of wind velocities and threshold velocities that include those postulated for the Martian surface. These erosion rates are shown in Figures A-6 to A-9. The ratios of mass eroded to mass impacted were taken directly from Figure A-1. Somewhat conservative values of  $2.5 \times 10^{-3}$  for lucite and  $1.5 \times 10^{-3}$  for aluminum were used. Other parameters are as marked on the individual figures. The effect of varying the threshold velocity  $v_\tau$  is shown in Figure A-10 for lucite, given that  $P = 2$  and  $\Phi(220) = 1 \times 10^{-4} \text{ oz/ft}^3$ . Similar curves result for aluminum.

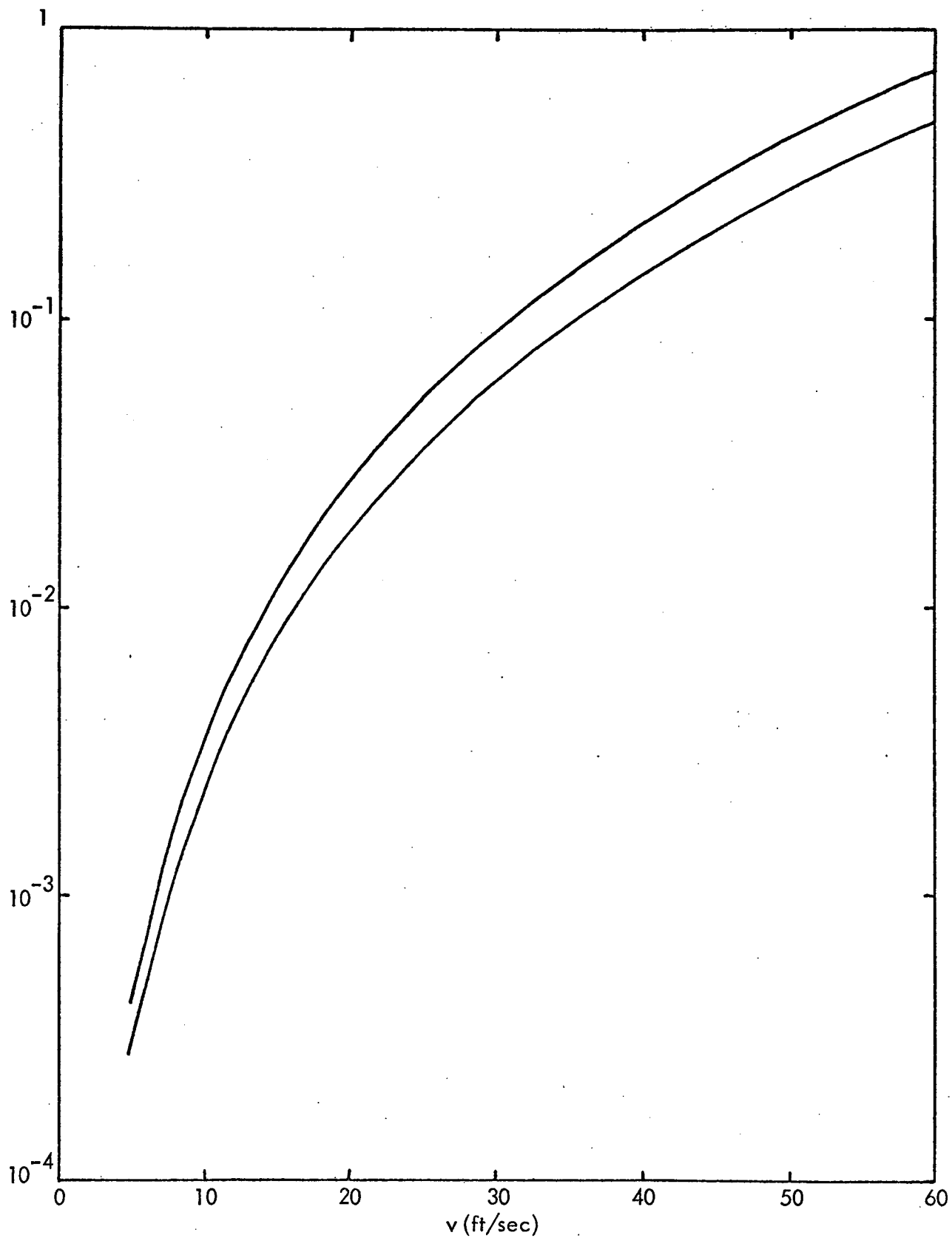


Figure A-6. Erosion Rate for Lucite

Given:  $P = 1$  and  $v_T = 0$

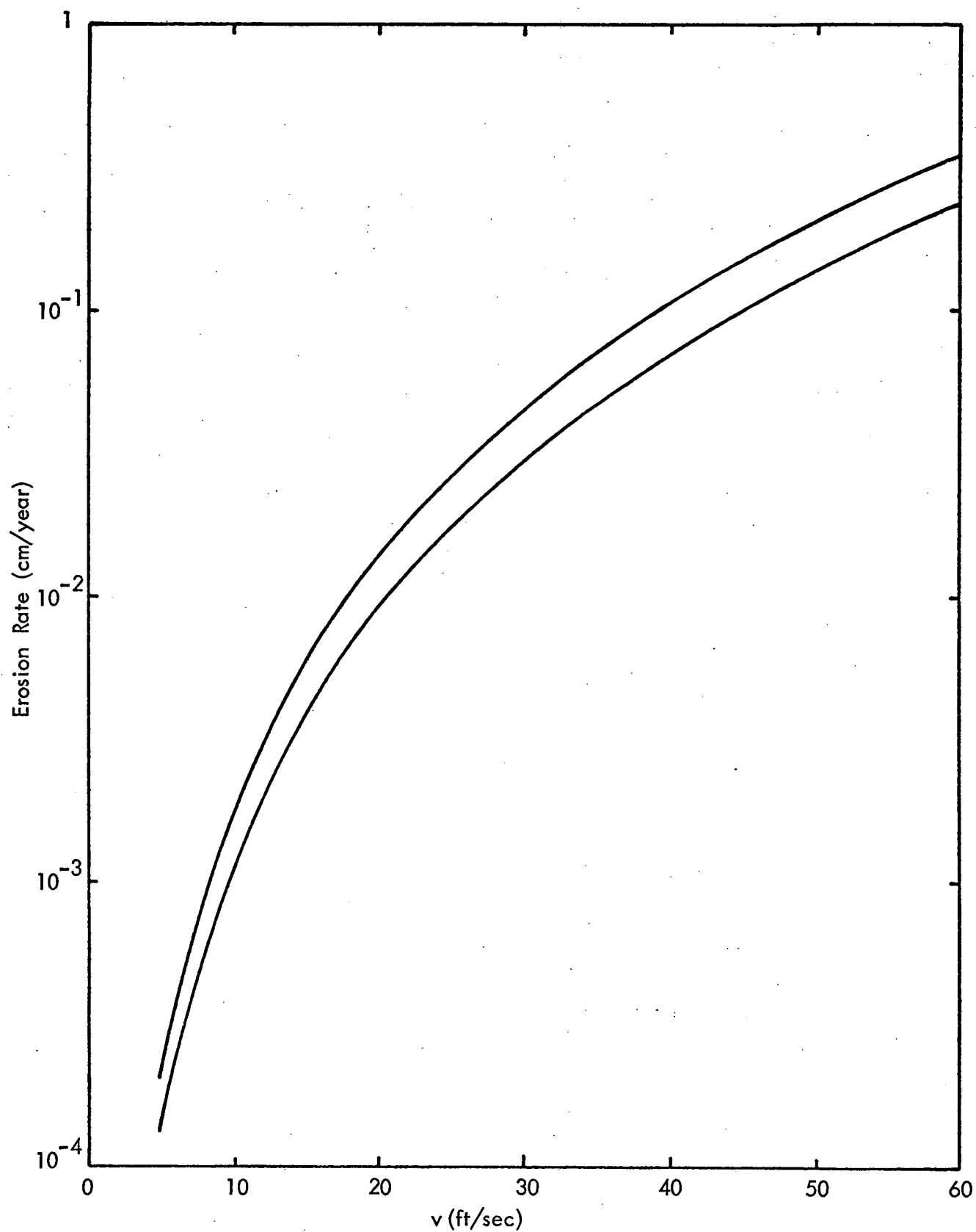


Figure A-7. Erosion Rate for Aluminum

Given:  $P = 1$  and  $v_T = 0$

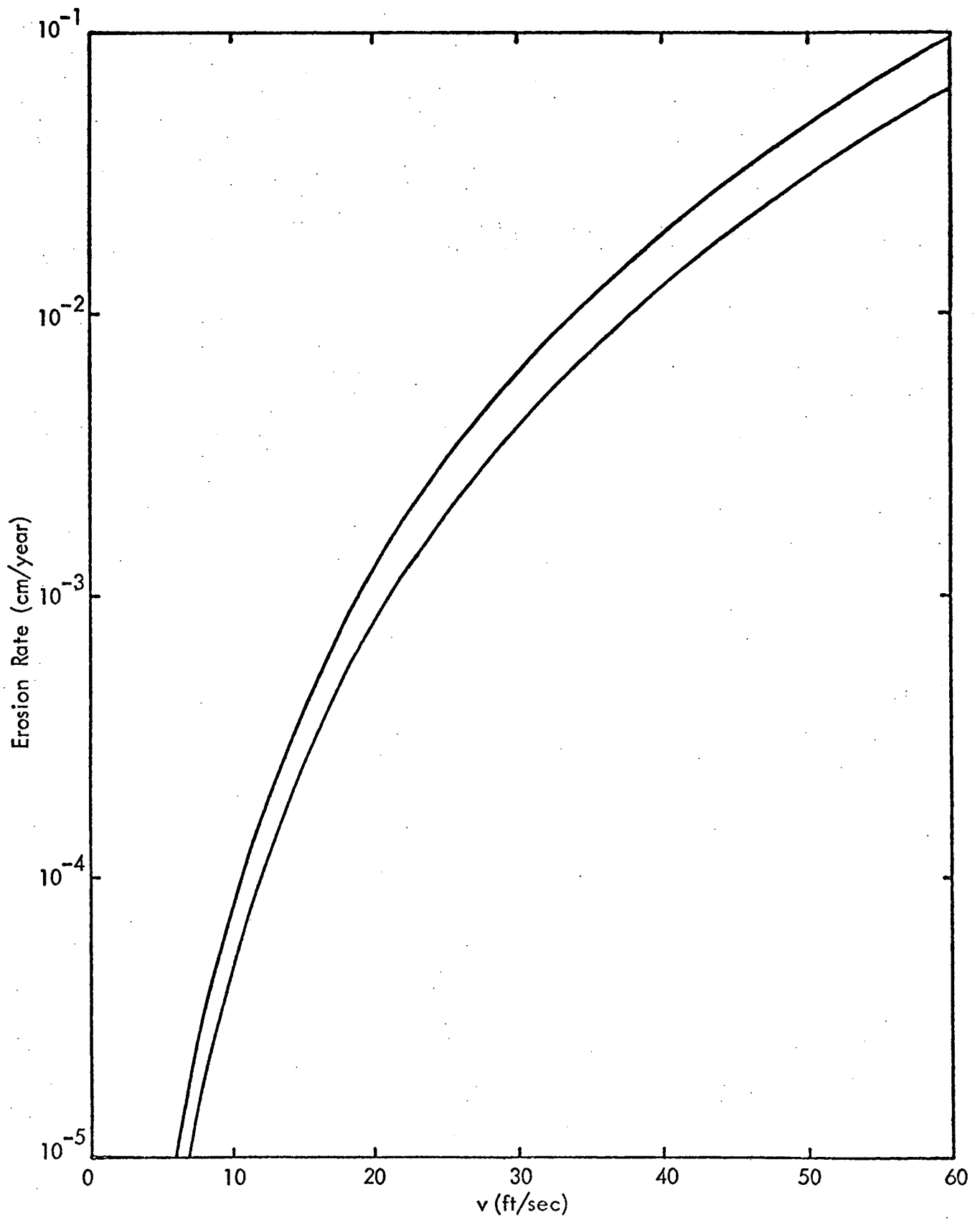


Figure A-8. Erosion Rate for Lucite

Given:  $P = 2$  and  $v_{\tau} = 0$

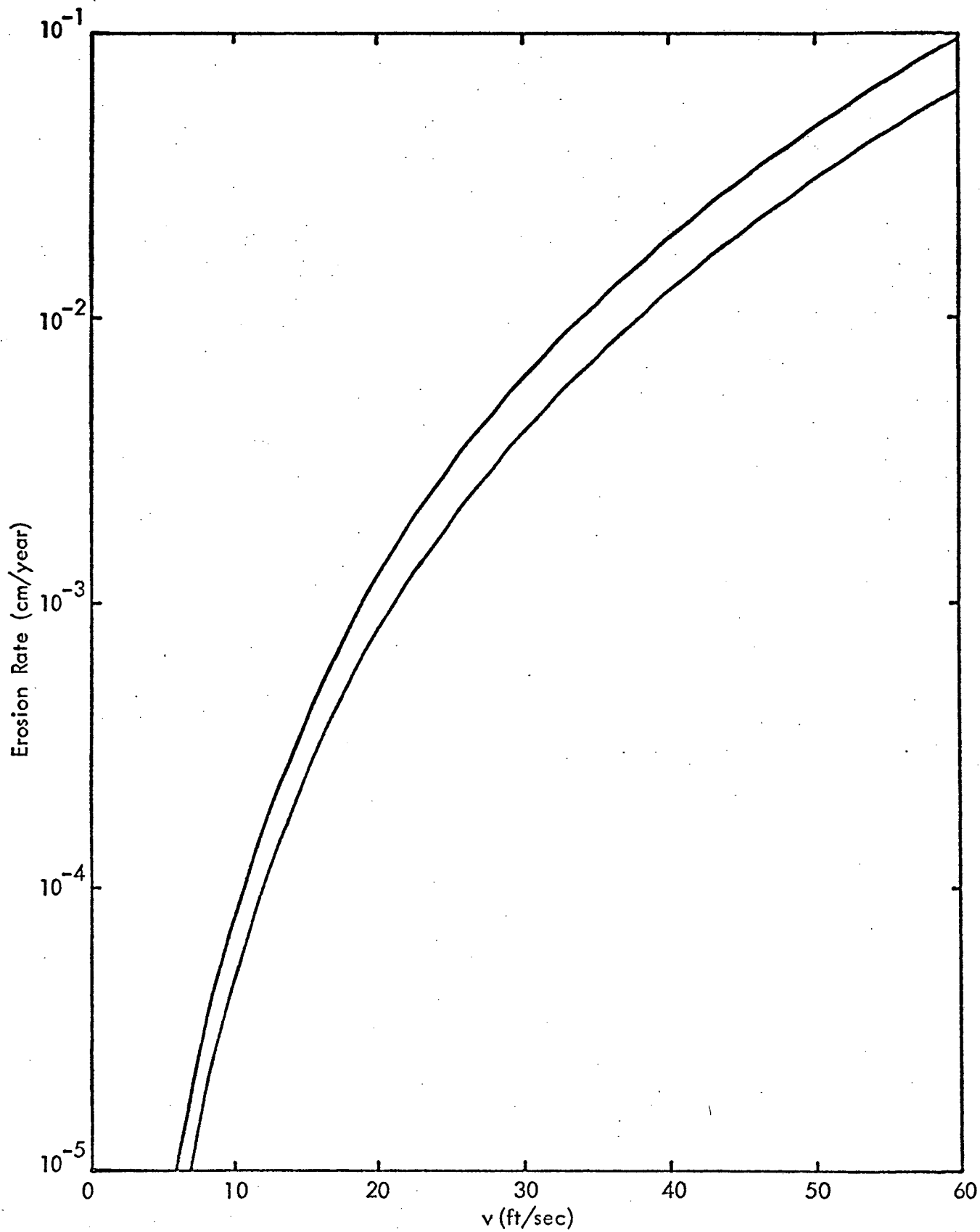


Figure A-9. Erosion Rate for Aluminum

Given:  $P = 2$  and  $v_{\tau} = 0$

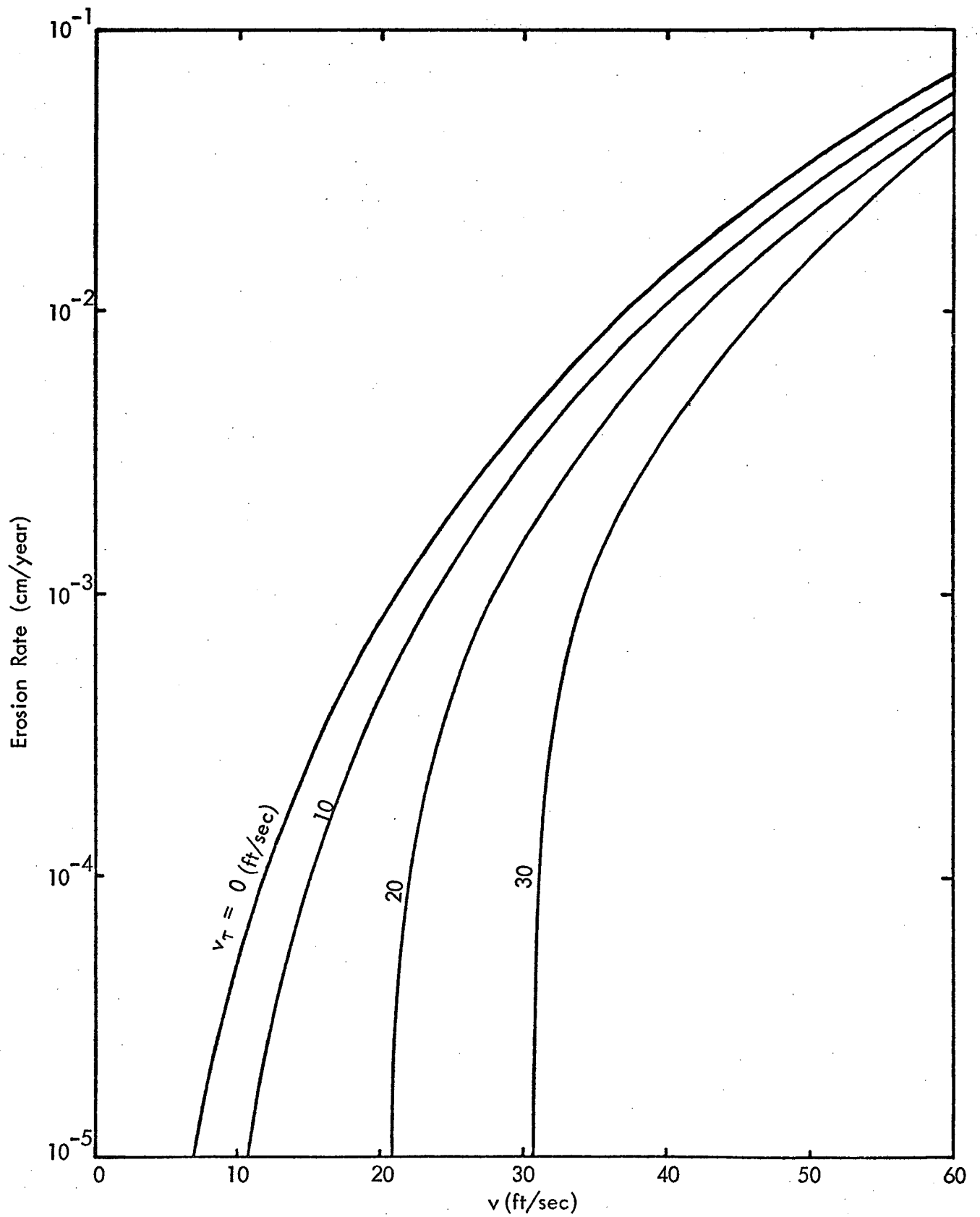


Figure A-10. Erosion Rate for Lucite,  
Given Various Values of  $v_\tau$ ,  $P = 2$ , and  $\Phi(220) = 1 \times 10^{-4}$  oz/ft<sup>3</sup>

## REFERENCES

1. Neilson and Gilchrist: Erosion by a Stream of Solid Particles. *Wear*, vol. 11, Feb. 1968, pp. 111-122.
2. Adlon, G.L.; and Rusert, E.L.: Effects of Simulated Mars Dust Erosion Environment on Thermal Control Coatings. *J. Spacecraft*, vol. 7, no. 4, April 1970, pp. 507-510.
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5. Anon.: Viking 75 Project—Mars Engineering Model. NASA/Langley Research Center, Document M75-125-1, Dec. 1970.
6. Sagan, C.; and Pollack, J.B.: A Windblown Dust Model of Martian Surface Features and Seasonal Changes. Smithsonian Astrophys. Observatory Special Report 255, Nov. 1967.

**APPENDIX B**

**PLANETARY QUARANTINE**

**PARAMETER VALUES**

$P_B(\text{re}|s)$   
SYMBOL

MARS  
MISSION SPECIFIC

UPPER

$1 \times 10^{-4}$   
ACCEPTABLE

LC

PLANETARY QUARANTINE PARAMETER VALUE

PARAMETER TITLE:

PROBABILITY OF RELEASE BY EROSION OF ENCAPSULATED (BURIED)  
MICROORGANISMS UNDER SOFT LANDING CONDITIONS

PARAMETER DEFINITION:

Assuming soft landing of a spacecraft on Mars, probability that a randomly selected buried microorganism within a defined source, will be removed from that source by aeolian erosion and deposited on the surface of the planet in a viable state.

APPLICABLE SOURCE:

All microorganisms encapsulated within non-metallic spacecraft materials.

CONSTRAINTS:

This value was derived assuming the use of heat sterilization. If processes are proposed that do not include heat, the value must be reassessed to assure its applicability for the proposed usage.

This value is based upon environmental conditions predicted by preliminary results from the Mariner 9 mission. The value of this parameter may have to be revised on the basis of further results from the Mariner 9 mission.

REFERENCES:

PQAP review on January 18-19, 1972 at Cape Kennedy, Florida.

*Lawrence B. Hall*  
PLANETARY QUARANTINE OFFICER

MAR 2 1972

DATE

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P<sub>s</sub>(re|s)  
SYMBOL

MARS  
MISSION SPECIFIC

1  
UPPER

see  
below  
ACCEPTABLE

PLANETARY QUARANTINE PARAMETER VALUE

PARAMETER TITLE:

PROBABILITY OF RELEASE BY EROSION OF SURFACE ORGANISMS  
UNDER SOFT LANDING CONDITIONS

PARAMETER DEFINITION:

Assuming soft landing of a spacecraft on Mars, probability that a randomly selected surface organism within a defined source will be removed from that source by aeolian erosion and deposited on the surface of the planet in a viable state.

APPLICABLE SOURCE:

All microorganisms on spacecraft surfaces.

CONSTRAINTS:

Selection of a particular value within the above bounds shall be based on the relative accessibility of the surfaces under consideration to aeolian erosion. A value of 1 shall be used for exposed, external surfaces. Smaller values can be justified for surfaces which are shielded from exposure by protective material. Interior surfaces on remotely located containers with covers of erosion-resistant materials can use values near the lower limit.

This data was derived assuming the use of heat sterilization. If processes are proposed that do not include heat, the value must be reassessed to assure its applicability for the proposed usage.

This value is based upon environmental conditions predicted by preliminary results from the Mariner 9 mission. The value of this parameter may have to be revised on the basis of further results from the Mariner 9 mission.

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$P_B(r|I)$   
SYMBOL

MARS  
MISSION SPECIFIC

UPPER

$1 \times 10^{-4}$   
ACCEPTABLE

PLANETARY QUARANTINE PARAMETER VALUE

PARAMETER TITLE:

PROBABILITY OF RELEASE OF BURIED ORGANISMS UNDER NON-NOMINAL LANDING CONDITIONS

PARAMETER DEFINITION:

Assuming non-nominal landing velocities of the spacecraft on Mars, probability that a randomly selected organism encapsulated within spacecraft materials will be removed by the combined mechanisms of fracture during impact and subsequent erosion, and deposited on the surface of the planet in a viable state.

APPLICABLE SOURCE:

All encapsulated microorganisms on the spacecraft.

CONSTRAINTS:

Conditional that the cumulative probability of events leading to impact at velocities more than 1,000 feet/sec is at least five decades smaller than the cumulative probability of all events leading to non-nominal landing velocities.

This value was derived assuming the use of heat sterilization. If processes are proposed that do not include heat, the value must be reassessed to assure its applicability for the proposed usage.

This value is based upon environmental conditions predicted by preliminary results from the Mariner 9 mission. Should later data suggest that these predictions be changed, the value of this parameter may have to be revised.

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PLANETARY QUARANTINE PARAMETER VALUE

PARAMETER TITLE:

PROBABILITY OF RELEASE OF SURFACE ORGANISMS UNDER NON-NOMINAL LANDING CONDITIONS

PARAMETER DEFINITION:

Assuming non-nominal landing velocities of the spacecraft on Mars, probability that a randomly selected organism located on a surface will be removed by the combined mechanisms of impact and subsequent aeolian erosion and deposited on the surface of the planet in a viable state.

APPLICABLE SOURCE:

All surface organisms on the various spacecraft surfaces.

CONSTRAINTS:

Conditional that the cumulative probability of events leading to impact at velocities more than 1,000 feet/sec is at least five decades smaller than the cumulative probability of all events leading to non-nominal landing velocities.

This value was derived assuming the use of heat sterilization. If processes are proposed that do not include heat, the value must be reassessed to assure its applicability for the proposed usage.

This value is based upon environmental conditions predicted by preliminary results from the Mariner 9 mission. Should later data suggest that these predictions be changed, the value of this parameter may have to be revised.

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$P_M(\text{re}|s)$

SYMBOL

MARS

MISSION SPECIFIC

UPPER

$1 \times 10^{-3}$

ACCEPTABLE

LOWER

PLANETARY QUARANTINE PARAMETER VALUE

PARAMETER TITLE:

PROBABILITY OF RELEASE BY EROSION OF MATED  
MICROORGANISMS UNDER SOFT LANDING CONDITIONS

PARAMETER DEFINITION:

Assuming soft landing of a spacecraft on Mars, probability that a randomly selected mated microorganism within a defined source will be removed from that source by erosion and deposited on the surface of the planet in a viable state.

APPLICABLE SOURCE:

All organisms on mated surfaces of the spacecraft.

CONSTRAINTS:

This value was derived assuming the use of heat sterilization. If processes are proposed that do not include heat, the value must be reassessed to assure its applicability for the proposed usage.

This value is based upon environmental conditions predicted by preliminary results from the Mariner 9 mission. The value of this parameter may have to be revised on the basis of further results from the Mariner 9 mission.

REFERENCES:

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MARS

SYMBOL

MARS

MISSION SPECIFIC

1x10

UPPER

ACCEPTABLE

LO

PLANETARY QUARANTINE PARAMETER VALUE

PARAMETER TITLE:

PROBABILITY OF RELEASE OF MATED ORGANISMS UNDER NON-NOMINAL LANDING CONDITIONS

PARAMETER DEFINITION:

Assuming non-nominal landing velocities of the spacecraft on Mars, probability that a randomly selected mated organism anywhere in the spacecraft will be removed by the combined mechanisms of fracture during impact and subsequent erosion, and deposited on the surface of the planet in a viable state.

APPLICABLE SOURCE:

All mated organisms on the landing vehicle.

CONSTRAINTS:

Conditional that the cumulative probability of events leading to impact at velocities more than 1,000 feet/sec is at least five decades smaller than the cumulative probability of all events leading to non-nominal landing velocities.

This value was derived assuming the use of heat sterilization. If processes are proposed that do not include heat, the value must be reassessed to assure its applicability for the proposed usage.

This value is based upon environmental conditions predicted by preliminary results from the Mariner 9 mission. Should later data suggest that these predictions be changed, the value of this parameter may have to be revised.

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$d_v(u)$	ALL	150/cc	130/cc	1/c
SYMBOL	MISSION SPECIFIC	UPPER	ACCEPTABLE	LOWER

PLANETARY QUARANTINE PARAMETER VALUE

PARAMETER TITLE:

AVERAGE ENCAPSULATED MICROBIAL DENSITY

PARAMETER DEFINITION:

The average number of microorganisms buried inside non-metallic unit volume of the spacecraft. The value does not take into consideration any burden reduction during spacecraft manufacture, assembly and test.

APPLICABLE SOURCE:

Total volume of non-metallic materials in the spacecraft; or a major part thereof containing piece parts, and non-metallic materials of similar properties to the entire spacecraft.

CONSTRAINTS:

To apply this parameter, the total volume of non-metallic material must be derived.

This value was derived assuming the use of heat sterilization. If processes are proposed that do not include heat, the value must be reassessed to assure its applicability for the proposed usage.

REFERENCES:

-- PQAP review on September 28, 1971 in Denver, Colorado

*Y B H*

PLANETARY QUARANTINE OFFICER

*Mar 2 1972*  
DATE

NOTE: THE ABOVE DATA SUPERCEDES PREVIOUSLY PUBLISHED DATA ISSUED BY THIS OFFICE. PARAMETER VALUES DERIVED AS STATED ABOVE WILL BE ACCEPTED BY THE PLANETARY QUARANTINE PROGRAM IF USED IN THE MISSION P.Q. ANALYSIS AS DEFINED HEREIN.

$d_v^j(0)$ 

SYMBOL

ALL

MISSION SPECIFIC

UPPER

SEE  
BELOW

ACCEPTABLE

LOWER

PLANETARY QUARANTINE PARAMETER VALUEPARAMETER TITLE:

SOURCE-SPECIFIC ENCAPSULATED MICROBIAL DENSITY

PARAMETER DEFINITION:

The average number of microorganisms buried inside designated subassemblies or other components of a spacecraft. The number can be expressed in terms of volume or area according to the application as specified below.

APPLICABLE SOURCE:

All non-metallic materials on the spacecraft.

CONSTRAINTS:

Values of this parameter are selected from the following categories and ranges depending upon the composition and manufacturing process for each designated source:

## Encapsulated organisms in:

Electronic piece parts

3-150/cm<sup>3</sup>

Other non-metallic materials

1-30/cm<sup>3</sup>

## Surface densities:

Clean room-highly controlled

0.05-0.5/cm<sup>2</sup>

Clean room-normal control

0.5-10/cm<sup>2</sup>

Uncontrolled manufacturing

10-100/cm<sup>2</sup>

This data was derived assuming the use of heat sterilization. If processes are proposed that do not include heat, the value must be reassessed to assure its applicability for the proposed usage.

REFERENCES:

PQAP review on September 28, 1971 in Denver, Colorado

JBH  
PLANETARY QUARANTINE OFFICERMar 2 1972  
DATE

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P(uv)  
SYMBOL

MARS  
MISSION SPECIFIC

1  
UPPER

see  
below  
ACCEPTABLE

<1  
LOW

PLANETARY QUARANTINE PARAMETER VALUE

PARAMETER TITLE:

PROBABILITY OF SURFACE ORGANISMS SURVIVING ULTRA-VIOLET RADIATION

PARAMETER DEFINITION:

Probability that a randomly selected organism on a surface exposed to extra-terrestrial ultra-violet radiation will survive the dose applicable to the mission specific conditions.

APPLICABLE SOURCE:

All organisms on surfaces exposed to extraterrestrial ultra-violet radiation.

CONSTRAINTS: Selection of a particular value is to be made in two steps as follows:

1. Assuming complete exposure of the microorganisms, i.e., no shielding, P(uv) is determined from a log-log linear function vs time of exposure to extra-terrestrial uv radiation. This function is determined by two points:  
(a) P(uv) = 1 for a time of exposure of one minute, or less, and  
(b) P(uv) =  $1 \times 10^{-4}$  for a time of exposure of one hour. P(uv) for times of exposure other than the above can be obtained by interpolation or extrapolation of these two points.
2. The value obtained in accordance with the above must be increased to allow for the effects of shielding by structures or by small particles such as dust and debris.

These data were derived assuming the use of heat sterilization. If processes are proposed that do not include heat, the values must be reassessed to assure applicability for the proposed usage.

REFERENCES:

PQAP review on January 18-19, 1972 at Cape Kennedy, Florida.

*Lawrence B. Nell*  
PLANETARY QUARANTINE OFFICER

MAR 2 1972

DATE

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